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SONOMA COUNTY, CALIFORNIA

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SPECIAL REPORT 134



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SPECIAL REPORT 134

EROSION ALONG DRY CREEK
SONOMA COUNTY, CALIFORNIA

By GEORGE B. CLEVELAND and FREDERIC R. KELLEY

1977

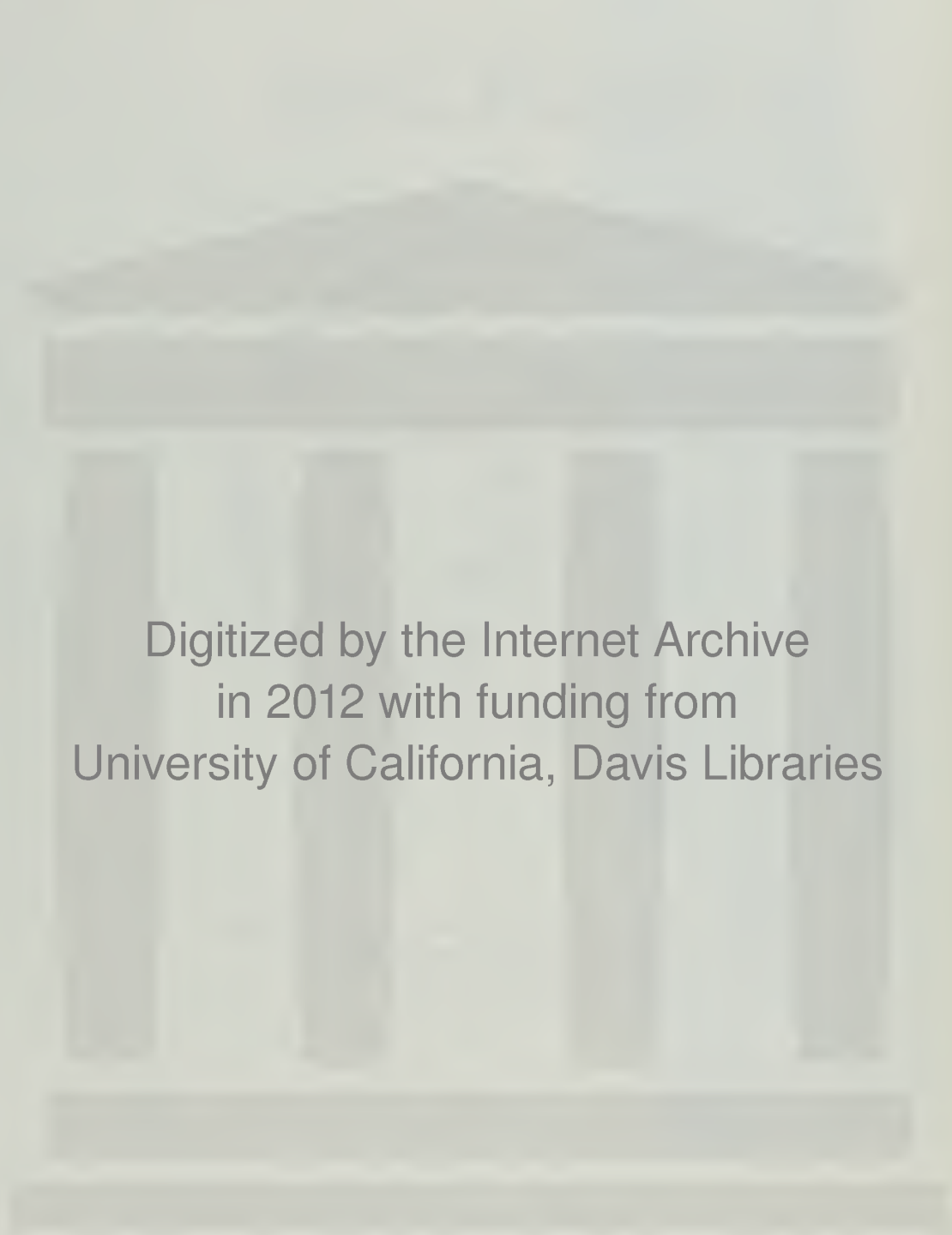
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EROSION ALONG DRY CREEK SONOMA COUNTY, CALIFORNIA

By GEORGE B. CLEVELAND and FREDERIC R. KELLEY

ABSTRACT

In recent years at least 87 acres of agricultural land have been lost by stream erosion along the lower 15 miles of Dry Creek in Sonoma County, California.

Erosion by lateral corrasion has occurred mainly along relatively narrow, flat reaches of the stream bed where thick deposits of gravels have accumulated. The gravel deposits crowd the stream against its banks which leads to local widening of the channel.

The erosion process has been accelerated by rapid runoff from record storms, an increase in normal runoff after the loss of protective vegetation by fire, and by the combined effect of loss of vegetation and flooding when a record storm closely followed a major fire.

Sand and gravel mining near the mouth of the creek has led to a significant lowering of the stream bed over a reach of about 1 mile.

INTRODUCTION

Rapid erosion along Dry Creek has been occurring in the 15-mile reach from its mouth at the confluence with the Russian River, northwestward to the Warm Springs dam site (figure 1; figure 2). Bank erosion resulted in the loss of at least 87 acres of agricultural land in the last 23 years.

Gravel mining in the Russian River channel and other nearby areas of the Russian River drainage basin has been an important industry in Sonoma County since the early 1900s. In recent years gravel mining has increased in Dry Creek channel and locally this has been considered to be one of the causes of increased erosion on Dry Creek. Between 1954 and 1974 incomplete records indicate that at least 1,457,000 tons of sand and gravel were mined on Dry Creek adjacent to Westside Bridge at Healdsburg.

Dry Creek is in the Russian River drainage system (figure 1). The headwaters of both Dry Creek and Russian River are in Mendocino County immediately north of Sonoma County. Dry Creek flows southeasterly down a valley which is approximately parallel to the Russian River and separated from it by a low range of hills. The floor of lower Dry Creek valley is relatively flat with some elevated terraces which mark former levels of the stream. The alluvial soil is fertile and the valley floor is covered with orchards and vineyards. Dry Creek joins the Russian River about 1 mile south of Healdsburg.

Numerous organizations have been concerned with erosion problems in the Russian River drainage basin in recent years. Among them are: (1) the Sonoma County Water Agency, (2) Sonoma County Board of Supervisors, (3) California Department of Fish and Game, (4) State Water Quality Control Board, (5) U.S. Army Corps of Engineers, and (6) U.S. Geological Survey.

The analysis of the Dry Creek erosion problem by the California Division of Mines and Geology is based on a review of previous work by others and on the results of a limited field investigation. The 15-mile reach of Dry Creek from its mouth at the Russian River below Healdsburg northwestward to near the site of the Warm Springs Dam, represents the reach of the creek where rapid erosion was noted and where this investigation has been mainly directed. However, a brief examination was made of the upper reaches of the drainage above the Warm Springs dam site.

Acknowledgments

We are indebted to the California Department of Forestry, Sonoma Ranger Unit, for information on recent fire history; to Obed Cramer and Peter Jackson of the U.S. Army Corps of Engineers for unpublished hydrologic and climatic data and photo mosaics of Dry Creek; and to the Sonoma County Water Agency for the loan of air photographs. Jack Rist, President of the Dry Creek Valley Association, and other local ranchers were particularly helpful.

REGIONAL SETTING

Evolution of the Russian River Drainage

Development of the general features of the present course of the Russian River system and its tributaries occurred during Pleistocene time. At that time, the main river developed a meandering course to the sea across a surface of low relief underlain by soft marine deposits that had only recently emerged by uplift. Higgins (1952) points out that as this surface slowly rose, the river maintained its meandering course as it cut into the rising land surface. Eventually the river cut down through the soft marine sands into the harder rocks of the Franciscan Formation and incised a vee-shaped gorge to the sea, retaining the general sinuous alignment of the original meanders.

The stream courses were well developed by the time of the Wisconsin stage of the Pleistocene (Higgins, 1952). Great amounts of water were stored in thick accumulations of continental ice resulting in a general lowering of sea level estimated at about four hundred feet. The Russian River graded its channel to this lower base level.

When temperatures increased following the Wisconsin stage the ice of the continental glaciers melted, leading to a rise in sea level, and the river and the lower parts of its tributaries began to aggrade their channels. The bottoms of the channels became clogged and the streams began to move laterally in broad meanders distributing gravel across the width of the valleys and leaving behind abandoned stream channels. A prolonged period of stable sea level and the absence of tectonic activity allowed the development of relatively level floodplains in the valley of the

Russian River and lower Dry Creek. Periodically floods overtopped the channel banks, spreading rich alluvial soils over the valley floor. This stable period lasted long enough so that some tributaries of Dry Creek, specifically Mill and Pena Creeks, developed meanders in their lower courses across the Dry Creek valley floodplain.

The most recent regional change in the evolution of this river system has been a net lowering of base level, either by drop in sea level or by regional uplift. Gealey (1951) noted a slight uplift during Holocene time had caused the Russian River to erode once more, and that it had already cut downward some 20 feet. Similarly, Dry Creek and its tributaries on the flat valley surface have become entrenched to about the same depth. The ancient downcutting of the meandering courses of Mill and Pena Creeks are preserved in steep-walled, flat-floored channels. Although Dry Creek channel winds somewhat normally, it does not exhibit well-developed meanders.

Precipitation and Runoff

The climate of this area is characterized by dry summers, with precipitation concentrated from October through April. Significantly, the rainfall pattern varies from year to year, with total precipitation being very light in some years and heavy in others. Widespread flooding has frequently occurred in the Russian River basin.

The Dry Creek channel carries little water during the summer. In the wet season, heavy and prolonged storms cause it to rise rapidly and become a powerful stream with considerable volume. Precipitation records from the Healdsburg and Cloverdale weather stations correlate closely with runoff records in the Dry Creek drainage area. But these comparisons were made only on an annual basis of total precipitation related to total runoff. Brown and Ritter (1971) state that the intensity and duration of each rainstorm has more effect on sediment transport (and by inference on bank erosion) than the total annual runoff.

Stream flow and suspended sediment are regularly measured at stream gauge stations. Measurement of the bed load—clasts moving downstream along the stream bed by traction and saltation—is a much more difficult problem (Hubbell, 1964, p. 71; Leopold, Wolman and Miller, 1964, p. 185). However, it seems reasonable in the Dry Creek drainage to expect that stream flows carrying large loads of suspended sediment are probably also moving large bedloads.

A stream-gauging station in Dry Creek valley at Yoakim Bridge, #11465200 (former #4652), is referred to as "Dry Creek near Geyserville." The measurements at this station began in 1960 and record flow from a drainage area of 162 square miles. For the water year 1974 (October 1973 through September 1974) measurements at station #4652 show a total annual runoff of 487,300 acre-feet. This was the highest of record and was preceded and followed by abnormally high runoffs in 1973 and 1975, following the lowest year of record, which was 1972.

Other excessively wet periods were recorded for water years 1965 and 1970. The record indicates that the maxima are building to higher values and the minima to lower values.

A longer record base is available for other stream-gauging stations in the region: (1) #11464000 (former #4640), Russian River at Healdsburg, drainage area 791 square miles; records date back to 1940; (2) #11464500 (former #4645), Dry Creek near Cloverdale, on upper Dry Creek just below Smith Creek; drainage area 88 square miles; records date back to 1942. In addition, a temporary station on Dry Creek at Bord Bridge provided records between 1940 and 1942. Data from these stations are shown on figure 3. The data are consistent with

the readings at Yoakim Bridge, and extend the Dry Creek statistics back 36 years.

The California Department of Water Resources (1965) has extrapolated the record back an additional 30 years. Available records from the gauging station at Van Arsdale Dam, in the Eel River drainage 50 miles to the north, were compared with the post-1942 readings for Dry Creek near Cloverdale. Computer derived estimated runoff for this station has extended the record back to 1911. These readings indicate flood runoffs in 1914, 1915, 1916, 1921, 1927, and the record flood of 1938 (December, 1937). Both the 1958 and 1974 runoffs were of about the same magnitude as the 1938 maximum.

Accounts of periodic flooding in the Russian River basin go back more than 100 years, so the pattern of periodic flood flows appears to be a long-time normal phenomenon for this region (McGlashen and Briggs, 1939).

Sediment Yield

Suspended sediment transport and its relation to turbidity in the Russian River system was investigated by Ritter and Brown (1971) and a study of the movement of sediment from source to site of deposition in Marin and Sonoma Counties was made by Brown and Jackson (1974). Following the 1964 flood, it was found that the average amount of suspended-sediment yield in the Russian River basin above Guerneville was 4370 tons per square mile of watershed area per year for the 4 years 1965 through 1968 (Ritter and Brown). Of the several tributaries in the Russian River basin, Dry Creek contributed the highest yield, averaging 5770 tons of suspended sediment per square mile per year. For the entire Russian River basin, more than half of the annual suspended-sediment load was transported in 6 days or less of heavy storm runoff, and for Dry Creek, most of the annual load was transported in 4 days.

It was concluded that transport of sediment in coastal northern California is affected more by the intensity and duration of each rainstorm than by the total annual quantity of rainfall. Measurements at the Cloverdale station northeast of Geyserville showed that total rainfall was about the same in 1965 and 1967, but that four times as much sediment was moved in 1965 as in 1967.

Ritter and Brown further concluded that the high sediment-transport yield in Dry Creek was a result of accelerated erosion in the watershed area brought on by detrimental early-day land-use practices. They cite an earlier U.S. Department of Agriculture study which pointed out that before settlement of the area in the 1870s, half of the watershed was forested. Some 40% of this woodland was cleared and converted to grazing land. Without the natural forest cover, erosion was greatly accelerated, and it was estimated that 42% of the sediment yield came from slope erosion of grazing land. Areas affected by logging, landslides, fires, and road-building contributed 15% of the sediment yield, and channel erosion accounted for the remaining 43% of the sediment yield.

Ritter and Brown found that 31% of the suspended-sediment load of Dry Creek is sand, but that in some tributaries in the Russian River basin where the flow is regulated, most of the suspended sediment is of finer grain size. This is consistent with simple hydraulic principles: increasing the velocity and volume of stream flow increases the transporting power of the water many fold, so that most of the suspended-sediment load would be moved in the short period of high velocity and high volume flood flow after a heavy storm.

Brown and Jackson (1974) summarize erosion factors and point out that accelerated upland erosion results in accelerated

deposition in the lowlands. More sediment gets into the streams than the streams can transport, and stream channels slowly fill, become shallower and wider, and have a greater tendency to flood and to erode previously stable channel banks.

Brown and Jackson (1974, p. 4) state: "...the Russian River [system] reflects a complex situation of channel adjustment to numerous interacting factors." Accelerated erosion has choked some reaches with gravel bars. Artificial channel constrictions, such as riprap and dikes, prevent the river from making natural adjustment, and it may then damage riparian property downstream in previously undisturbed areas.

The balance between channel scour and deposition is complex, and local problems require a basin-wide evaluation. Otherwise, remedial measures applied locally may create new problems at another location.

EROSION ALONG DRY CREEK

General Observation

Under natural conditions, the long profile of lower Dry Creek, which is determined largely by the depth of the bedload above the bedrock, may increase and decrease in elevation in space and time. Only where there is a net loss over its entire length is the stream considered to have generally lowered its channel. Moreover, observations of the cross section from place to place along Dry Creek indicate that the floor of the channel varies several feet in elevation from one bank to the other.

Only at Westside Bridge has there been significant degradation on lower Dry Creek (figure 4). Based on two measurements made along the creek a degradation of 11 feet has been observed. Measurements along the Russian River, which in terms of sediment yield is relatively less active than Dry Creek, indicate both increases and decreases in the elevation of the thalweg (the longitudinal profile line connecting the lowest points along the stream bed). In the lower reach of the Russian River, the thalweg increased 4 feet at one point and decreased 12 feet at another point. The thalweg in the middle reach decreased 9 feet at two localities and the upper reach increased 5 feet at one point and decreased 5 feet at another point (Sonoma County Water Agency, 1972). The greatest normal range recorded was 8 feet in the lower reach. This suggests that there is a normal range between aggradation and degradation for the river at different places along its course.

With respect to the lowermost reach of Dry Creek, survey data by the U.S. Army Corps of Engineers show a significant, somewhat uniform lowering of the thalweg in recent years (Peter Jackson, personal communication, 1976). However, these data also indicate that there is a normal range in the elevation of the thalweg over short distances along the creek. A review of survey data collected in 1974 at twenty-four 400-foot reaches along 14 miles of lower Dry Creek indicates that the elevation of the thalweg can range from as little as 0.4 feet to as much as 4.7 feet, but averages about 2 feet at three stations in each 400-foot reach (table 1). Moreover, while the thalweg may be being lowered, this is not reflected uniformly across the channel. As indicated by the data in table 1, the channel cross-section can be highly irregular. The average thickness of deposits above the elevation of the thalweg is about 8 feet, but deposits in some areas may be piled up as much as about 20 feet.

Surveys made by the U.S. Army Corps of Engineers for the years 1974 and 1975 at 71 stations indicate that the thalweg increased at 14 stations and decreased at 25 stations; 32 stations remained unchanged. With respect to the entire cross-section of

the channel, the creek aggraded at 9 stations, degraded at 27 stations, and remained unchanged at 35 stations. Plate 2 shows these changes at the 24 principal stations (ranges) established by the U.S. Army Corps of Engineers. The changes recorded in the thalweg ranged from 1 foot to 3 feet, but averaged about 1 foot; at one of the gravel pits at Westside Bridge a drop of 9 feet was observed (table 2).

Nature of Erosion

Erosion along the Dry Creek channel is manifested (1) as removal of the banks by lateral spreading of the stream flow and (2) by downcutting or vertical lowering of the stream bed. These two processes of erosion occur to some degree at the same time, but generally one process is more active than the other. Downcutting can broaden the channel if its depth reaches a critical point in terms of the shear strength of the bank materials. As the height of the bank increases, it will eventually reach a point where the bank cannot support its own weight and bank failure will occur, thus enlarging the channel.

Stream Deposits

The Dry Creek drainage subbasin represents an area of high stream energy within that part of the upper Russian River basin which lies above the mouth of Dry Creek. The Dry Creek subbasin equals 21% of the area of the upper Russian River basin, yet it supplied 34% of the peak discharge during the flood of 1964 (U.S. Army Engineer District, 1967). In the area of lower Dry Creek storm rainfall in the four-day period of the storm of 1964 reached 10 inches to 11 inches (U.S. Army Corps of Engineers, 1967).

Even in years of normal rainfall the highland area to the west of Dry Creek, which was once protected by a forest cover, is an important precipitation-collecting area. Annual precipitation ranges from 40 inches to 48 inches in the area immediately west of Dry Creek.

The profiles of tributaries that flow out of this area are relatively steeper than the profile of Dry Creek. With the high runoff that accompanies steeper gradients, these streams move a considerable volume of weathered debris down to Dry Creek. When this material reaches the main channel, the creek's normal carrying capacity is unable to move the debris and it becomes stalled for a time in the main channel. Subsequently, however, during periods of heavy flooding, the debris is picked up and carried downstream. When the flood waters recede, the creek again returns to its low carrying capacity and the bedload and part of the suspended load is deposited. Therefore, an energy threshold exists whereby the larger clasts in the bedload can be moved only by runoff from major storms.

When the channel is partially blocked by the introduction of new debris, the volume of the channel to accommodate runoff is reduced and the stream may be forced against one of its banks, leading to lateral corrosion (figure 5). This is especially apparent along narrow reaches of the channel. With channel volume reduced, a relatively smaller volume of flow is needed to erode the channel laterally. Moreover, the bedload in the channel being made up of relatively dense materials in the larger size ranges is much harder to erode than are the fine-grain materials of the terrace deposits. Therefore, relatively less stream energy is needed to carry away the finer material and the creek migrates farther into the terrace deposits until equilibrium is reached. Since future floods move the gravel deposits further downstream, the banks below may be locally subjected to lateral erosion where the gravel again becomes temporarily deposited.

The height of the banks at most places along the creek give the impression that the creek is downcutting to a considerable depth below the normal level of the stream bed. However, this condition is more apparent than real. It can be explained by how the stream erodes its banks. The banks are being cut into various levels of terraces which parallel the stream channel. As the stream channel widens, it encounters higher and higher terraces as it moves laterally away from the center of the channel. This, in turn, yields higher banks along the channel; higher banks give the false impression that the stream is cutting downward rather than mainly cutting laterally (figure 6).

Stream Gradient

Coarse gravels are deposited when the velocity of the stream is reduced. Deposition of coarse gravel can occur in two ways: (1) by a reduction in stream flow, such as would be expected when a storm has passed, or (2) along those reaches of the stream where the gradient is relatively more gentle. A gentler gradient may represent underlying resistant bedrock or the previous point of deposition of gravel as in (1) of figure 6.

When downcutting is initiated at some point along a stream course normally this change in base level is transmitted upstream with decreased vigor until a stable gradient is established. However, if in the processes of downcutting the knickpoint (abrupt change in the longitudinal profile), which is the vanguard of the new gradient, encounters resistant stream deposits or bedrock or a flattening of the established gradient by an extraordinary influx of weathered debris, the process will be slowed or temporarily stopped (Leopold and others, 1964, p. 258-259).

Along lower Dry Creek bedrock is exposed locally in the stream channel and the gradient flattens from place to place. Therefore, the effects of any change in local base level will be fixed within certain reaches of the stream course, at least within time periods significant to man.

Stream Flow

The hydrologic characteristics of lower Dry Creek suggest that it is a braided stream where the flow is riding on coarse gravels and moving back and forth across the channel, with the channel developing a few poorly formed meanders. The ratio of bankfull discharge to channel slope indicates equilibrium in the braided form, although the conditions along certain reaches approach those of a meandering stream. The channel slope ranges from about .4% to .1% and at bankfull conditions the channel discharges from about 10,000 to 15,000 cfs. For the gentler slopes (.1% and lower) and the given discharge rates, the stream closely approaches conditions that would favor meandering (Leopold and others, 1964). If this threshold is reached, the normal braided channel, which distributes its energy largely down the axes of the stream course, would throw part of its energy laterally against its banks. Once this geometry is established it would lead to a cycle of increased bank erosion.

Because certain reaches of the channel carry a thicker veneer of stream deposits, the gradient of these reaches is conducive to meandering. Although this is not the general situation for the entire lower part of Dry Creek, locally, where it does occur, stream erosion is more active on the cut banks of these features due to the shearing effect of the flow. The channel exhibits several cutoff meanders as well as reoccupied meanders, which are revealed by comparing air photographs taken at different times and which indicate a return locally to gentler stream gradients in recent years.

Former meanders are preserved on the terraces above the present Dry Creek channel. Their presence may be, in part, related to the finer-grained sediments into which the terraces have been cut. Channels veneered with fine silt and clay foster meandering (Tanner, 1968, p. 958). During flooding Dry Creek invades these old features and locally has assimilated them into its modern channel.

The channel as shown on 1959 air photographs was restricted along certain reaches (plate 3). Moreover these reaches, as shown on plate 2, had gentle gradients and thus accumulated thick deposits of gravel, further flattening the gradient. With a decrease in gradient the stream approached the hydrologic conditions that favor meandering, thus concentrating erosion at certain points in a cyclic pattern along opposing banks.

Riparian Vegetation

In the process of channel enlargement, riparian vegetation is undercut and temporarily lost and it may take many years for mature growth to become reestablished. The loss of vegetation exposes the banks to further attack by the stream. Moreover, to some degree, the character of the sedimentation on the floodplain is altered by the loss of the filtering effect of a dense buffer of vegetation. During flooding the stream flow reaches velocities which allow it to transport relatively large clasts. As bankfull conditions are exceeded and the floodplain is inundated, these larger particles may be held back by a screen of dense vegetation. The density of the vegetation will regulate the size and amount of sediment that will reach the surface of the floodplain. Where the vegetation is missing, as it is locally along Dry Creek, coarse gravels are deposited on the valuable agricultural floodplain adjacent to the creek.

ANALYSIS OF THE EROSION PROBLEM

Because a wide range of geologic, climatic, vegetative, and man-induced factors bear on the rate, degree, and nature of erosion along Dry Creek, these factors were examined to determine their relative influence on the apparent acceleration of erosion in recent years. The reference point in time for the study of regional geography was established at 1953 because modern topographic maps (scale 1:24,000) were made on the basis of aerial photographs taken in 1953. Features shown on these maps can be compared with features observed at present to identify changes that may bear on the erosion problem. Geologic maps, aerial photographs, and landscape photographs were also used to establish changes which have occurred in the Dry Creek drainage area.

Area Geography

The Dry Creek drainage basin covers an area of about 218 square miles of which 130 square miles lie above the site of Warm Springs Dam and 88 square miles lie below the dam site in the area where stream bank erosion has caused property loss. The basin above the dam site is the principal source of precipitation and runoff that eventually flows into the lower reaches of Dry Creek (plate 1).

In the upper part of the basin sheet erosion is taking place at a rapid rate. Hilltops locally are devoid of heavy vegetation and support only a cover of grass. Numerous landslides are concentrated along the main channel of Dry Creek and locally along its tributaries. The debris from sheet erosion and landslides chokes Dry Creek and contributes the main sediment load which subsequently moves down the channel and spreads out onto the rela-

tively flat-bottomed valley of lower Dry Creek or is carried into the Russian River channel. This surface, or floodplain, ranges from about 1/3 mile to 1 mile in width. The gentle gradient has allowed the creek to swing back and forth into a series of irregular curves until it reaches a point about 4 miles from its mouth, where the channel becomes relatively straight.

The channel of Dry Creek is not uniform in width. Air photographs taken in 1959 indicate that the channel ranges in width from less than 100 feet to several hundred feet. Along most of lower Dry Creek the channel can accommodate a flow of 10,000 to 15,000 cubic feet per second. On the average, Dry Creek will reach bankfull conditions once every 2 years; during a 100-year storm the runoff would amount to about 2½ times that of bankfull conditions (U.S. Army Corps of Engineers, 1967).

The lower reaches of Dry Creek are bounded on the southwest by a low range of hills which reach elevations nearby of about 1500 feet. To the northeast, a low range of hills with maximum elevation about 900 feet separates the Dry Creek drainage from the main valley of the Russian River. The hills to the southwest of Dry Creek valley constitute a considerable local rainfall-collecting area and runoff enters lower Dry Creek from a total of thirteen drainage courses on both sides of the valley (plate 1).

The floodplain of Dry Creek is flat with a few terraces that can be traced discontinuously along the lower part of the creek. Other intermediate terraces are preserved locally, but the boundary between one terrace and the next is often obscured because of modifications of the land by agriculture. The lowermost terrace lies from 5 to 6 feet above the present stream level and is commonly inundated during periods of high water.

The general thalweg (longitudinal profile) of the creek rises from an elevation of about 70 feet at its mouth to about 220 feet in the vicinity of the Warm Springs Dam site. The profile can be divided into five main segments; three segments have a relatively gentle slope and two segments have a relatively steep slope (plate 2). The steeper segments of the profile are nearly twice as steep as the most gentle segments. Field evidence suggests that the steeper segments represent sections where the bedrock is either exposed or near the surface below a thin veneer of stream deposits. Coarse-grained stream deposits, in the form of gravel bars, tend to accumulate along the gentler stretches of the stream bed. The stream at low flow winds from side to side in the gravel-lined trough.

Mature riparian vegetation protects the banks of the creek from erosion along about half its length. Some trees are as much as 18 inches in diameter. The vegetation is limited generally to one side or the other, and only along a few short reaches is it preserved on both sides. The lowermost reach above the mouth is almost entirely devoid of mature growth.

Timber stands in the Dry Creek drainage basin have been harvested through the years. However there is some doubt as to just how much of the basin was timbered, and how much of the timber has been logged off. The U.S. Army Corps of Engineers (1967, p. 7) reported most of the basin was covered with timber and less than 5% remains; the U.S. Department of Agriculture estimated that half of the watershed was covered by Douglas Fir and redwood and about 60% of the stand remains (Ritter and Brown, 1971, p. 28).

Recent Events Related to Erosion

Between the years 1953 and 1975, but mainly from 1959 to 1975, a minimum of 87 acres of land has been eroded away along Dry Creek and the area has become part of the active channel of lower Dry Creek (figures 2, 7). The eroded acreage included various types of land, from soil-covered valuable agricultural

acreage to gravelly, previously abandoned parts of the creek's modern channel. Much of the agricultural land lost was from low-lying areas such as terraces and cut-off meanders adjacent to the modern channel.

Since 1953 several events have occurred that could bear on the cause of the erosion problem:

1. Sand and gravel mining has been accelerated along Dry Creek at Westside Bridge near Healdsburg.
2. There have been four fires in the tributary drainages of Dry Creek during the years 1959, 1964, 1970, and 1972 (table 3). The 1964 and 1972 fires were the most significant. The 1972 fire reburned a part of the area burned over by the 1964 fire.
3. There have been five major floods during water years 1956, 1962, 1963, 1965, and 1974 (table 3). The flood of 1965 was somewhat larger than that of 1956, but these two floods were the largest of record until the flood of 1974 (U.S. Army Corps of Engineers, 1967; Ritter and Brown, 1971). These five floods, which were the greatest of record, correlate closely in time with the major fires that have occurred adjacent to Dry Creek. One flood occurred within a few months of a fire and the others occurred within a few years of a fire.
4. At numerous places along Dry Creek, the natural channel has been modified by property owners. At various times since the turn of the century, levees were built and natural slopes were armored with all manner of material from junked automobiles and broken concrete to large boulders.
5. Construction of the Warm Springs flood control project on Dry Creek was begun in 1967 by the U.S. Army Corps of Engineers. A bridge was completed and part of the fill for a dam was emplaced. The dam was designed to be over 380 feet high with a capacity of 380,000 acre-feet. Construction was halted by court order in 1974 prior to completion.

Sand and Gravel Mining

Significant downcutting along Dry Creek can be demonstrated in the vicinity of the Westside Bridge near Healdsburg. Riparian vegetation that normally grows at the water line is now perched from 10 to 11 feet above the surface of the stream near the bridge. Also, along the creek upstream from the bridge, riprap used for armoring the banks is locally perched as much as 8 feet above the surface of the creek. Farther upstream the amount of downcutting steadily decreases to where there is no apparent field evidence of it about 1 mile above the bridge.

Between the years 1954 and 1974 incomplete records indicate that at least 1,457,000 tons of sand and gravel have been mined by two mining operations at Westside Bridge (Sonoma County Water Agency, 1972).

The channel conditions at Westside Bridge indicate that the two sand and gravel operations, one on the south side of the bridge and one on the north side of the bridge, have contributed to erosion along a 1-mile reach of the creek. Sand and gravel had been removed from these two localities for many years prior to any observations that indicated an acceleration of erosion. However, in recent years the rate of removal of sand and gravel has increased (figure 8). The material is being removed by drag line from irregular pits; the larger operation is on the north side of the bridge. It appears that the normal transport of debris by Dry Creek during the early years of these developments replenished the sand and gravel that was removed. However, as operations were accelerated on the upstream side of the bridge, the material was removed at a faster rate than it could be replenished. Secondly, the accelerated removal of gravel from this pit prevented any excess gravel from being carried downstream to

replenish the lower gravel pit. Inasmuch as the lower gravel pit was being enlarged faster than it was being replenished a knickpoint probably developed which migrated upstream past the bridge and the two pits merged. The combined removal of material by the two operations lowered the thalweg at the bridge and created a local base level. This initiated a knickpoint at the north end of the operations which has subsequently migrated about 1 mile upstream. While the thalweg has been lowered at the bridge, significantly, it is not a point where large scale broadening of the channel has occurred.

The removal of sand and gravel from the channel increases the volume of the channel available to carry larger amounts of runoff. Therefore, these operations may have actually reduced the likelihood of stream bank erosion to some degree. Apparently the gravel mining operations have not had any effect on the increase in erosion that has occurred more than 1 mile upstream from the bridge.

Flooding and the Fire-Flood Sequence

Considering the sensitive nature of the Dry Creek drainage basin with respect to erosion, it is not surprising that Dry Creek is enlarging its channel to accommodate a greater volume of weathered debris. During the flood year 1964, 2,283,000 tons of suspended sediment was measured passing at Yoakim Bridge on lower Dry Creek; 90% of the suspended sediment was transported in 7 days (Ritter and Brown, 1971, p. 24 and 27). The loss of slope stabilizing vegetation over broad areas through the years by changes in land use has apparently led to steadily increasing erosion rates, even under normal rainfall conditions. The problem has been aggravated in recent years by the greatest floods of record. All of these floods have occurred during about the last 20 years which is the approximate period of time that local property owners have noted an increase in bank erosion.

In addition to these floods, four fires have occurred adjacent to Dry Creek in tributary basins. These fires have locally destroyed secondary growth that was a stabilizing influence on weathered slope debris. The loss of vegetation and the high precipitation rates have led to rapid runoff. The high energy developed by these conditions has introduced coarse-grained debris into Dry Creek adjacent to the burned-over areas. The magnitude of flooding and the close correlation in time between the flooding and the fires is shown in table 3 and figure 9; the distribution of the fires is shown on plate 1. Generally it takes about 10 years for vegetation to recover from a fire; many factors, however, regulate the recovery time and some areas never recover their original density of vegetation.

Modification of Dry Creek Channel

The building of levees and the placing of erosion resistant materials against the banks of Dry Creek by numerous property owners to protect their land, has modified the natural course of the creek. Along cut banks and some other places where the banks have been armored to prevent erosion, the stream flow appears to have been diverted across the channel to the opposite bank. Thus, the erosion problem has been transferred by one property owner to another. To establish the influence of these protective works on channel morphology would require a detailed analysis at the various places where artificial materials have been placed.

Warm Springs Dam

Fill material for the dam was taken from the hills to the north above the dam site. The fill was placed on the north side of Dry Creek; it extends into the creek about two-thirds of the distance

to the opposite bank. Because the upper reaches of Dry Creek will be inundated by the reservoir behind the dam, the road up Dry Creek was rerouted to the south. This necessitated the building of a bridge across Warm Springs Canyon, a tributary which reaches Dry Creek just above the dam.

Even though dam construction was abruptly stopped some remedial measures were taken to reduce erosion from the stripped off terrain above the site to the north. Examination of air photos of the dam site taken in 1975 indicates some erosion has occurred from the source area of the fill and in the vicinity of the bridge. Little or none of the eroded material has reached Dry Creek from the north. An unknown insignificant amount of eroded debris has reached Warm Springs Creek from the slopes below the bridge. No significant amounts of fill have been eroded from the dam itself.

Representative Problem Area on Dry Creek

About 1.5 miles upstream from Westside Bridge, bank erosion has been particularly extensive. One property owner kept a record of erosion from 1955 through 1967 in the form of a map and photographs, which show the changes in the stream course during that period.

Photographs taken in 1960 show several generations of fence-like structures built of pilings cabled together to prevent erosion along the west side of Dry Creek and on the south side of Pine Ridge Creek (figure 7A, 7B). The pilings along Dry Creek are about 1 foot in diameter and stand about 5 feet above the surface of the stream. Adjacent banks, along which the erosion is taking place, appear to be at about the same height as the tops of the pilings. On the flat surface extending back from the bank young trees have been planted. These features indicate that the property was developed on the first or lowest terrace along Dry Creek. This is the terrace that is normally inundated during periods of flooding. A picture taken 15 years later from approximately the same location shows that this entire terrace surface has been removed by erosion and the orchard has been lost (figure 7C).

Pine Ridge Creek borders this property on the north where it enters the main course of Dry Creek. This tributary drains an area of about 1 square mile and during flooding it carries coarse debris to Dry Creek. About 1900 a levee was built, not only along Dry Creek, but also for a considerable distance up Pine Ridge Creek to protect low-lying terrace surfaces from flooding. Apparently the flow from Pine Ridge Creek augmented that of Dry Creek and contributed to local erosion along Dry Creek proper. The loss of land was recorded on a yearly basis from 1955 through 1967. No changes were recorded in 1961 and only a very small change was noted in 1962. From 1962 to 1965 little or no change was recorded. However in 1965 the largest single loss was recorded on the south side of Pine Ridge Creek. It was during the 1965 water year that the second largest flood of record occurred in the Dry Creek drainage. The numerous generations of pilings that were placed along Dry Creek and also along Pine Ridge Creek were defeated by flood waters flowing in behind them. This loss of acreage along Pine Ridge Creek where it joins Dry Creek suggests that a large part of the erosion was caused by runoff from Pine Ridge Creek and not solely from the flow of Dry Creek.

SUMMARY STATEMENT AND CONCLUSIONS

The evolution of a stream channel is a complex geologic process. The stream may change in volume and velocity; scour its banks or channel bottom at one locality, and deposit eroded

material at another. During floods, tributaries contribute eroded debris and increase the water volume in the main channel, often diverting its flow to a new course on its floodplain. In all, it is a dynamic process that seldom reaches a steady state.

In the lower Dry Creek drainage a series of geologic and climatic events in recent years has led to the acceleration of bank erosion. In the broad span of geologic time these events are normal and expected, but occurring as they have, within a relatively few years and in an area where the effects can be readily measured by the number of orchard trees lost, the situation appears ominous. Because of the long-term changes in land use in this region and the random occurrence of fires and flood, bank erosion will occur periodically from place to place along lower Dry Creek.

From this investigation it is concluded that:

1. Most of the erosion along the lower reaches of Dry Creek is caused by normal geologic processes. Between the years 1953 and 1975 a minimum of 87 acres of mainly agricultural land has been eroded away along lower Dry Creek.
2. Lateral erosion is the principal cause of channel widening. It is concentrated along relatively narrow reaches of the channel where thick deposits of gravel have accumulated.
3. Downcutting or stream degradation occurs mainly from the mouth of Dry Creek to a point 1 mile upstream from Westside Bridge. The downcutting of the channel upstream from the bridge appears to be related to the mining of sand and gravel at the bridge.
4. Erosion has accelerated in recent years because of abnormal runoff from record storms.
5. Wildfires in the hills adjacent to Dry Creek on the west have destroyed vegetation that protected slopes and this locally has contributed to the acceleration of erosion.
6. The fire-flood sequence has compounded the erosion problem by leaving the ground unprotected during heavy rainfall which permits high-energy stream flow to transport coarse gravels to Dry Creek.
7. The gentle gradient of lower Dry Creek normally prevents the generation of sufficient energy by the stream to purge itself quickly and uniformly of weathered debris supplied from tributary drainages.
8. Knickpoint migration would be significantly slowed at various places along the creek by the presence of bedrock at the surface or by thick accumulations of coarse gravel.
9. Riparian vegetation controls bank erosion and, to a degree, the nature of the sediments deposited on the floodplain.

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Table 1. Channel morphology, Dry Creek, Sonoma County, California. Data from U.S. Army Corps of Engineers (1974).

Elevation of Thalweg (ft.) ²					Elevation Range Across Channel Above the Thalweg (ft.) ⁴		
Station No. ¹	up-stream	at station	down-stream	maximum difference ³	upstream	at station	downstream
Bord Bridge	-	187.2	188.6	1.4	-	5.6	0.0
2	190.1	190.0	190.5	0.5	1.5	0.5	2.4
2A	188.7	189.0	189.1	0.4	3.8	1.5	5.0
4	181.3	181.8	181.4	0.5	5.8	7.8	4.6
5	172.1	170.8	169.1	3.0	1.5	2.7	3.5
7	166.0	166.1	164.4	1.6	6.6	5.9	6.4
8	162.5	162.5	161.5	1.0	1.7	4.2	3.4
Yoakim Bridge	162.7	160.5	158.5	4.2	1.1	4.3	8.2
11	153.3	153.7	152.7	1.0	3.8	5.1	8.5
13	145.7	146.3	145.9	0.4	2.9	2.4	2.8
15	143.1	141.2	138.6	4.5	2.1	2.8	7.1
18	132.4	130.8	130.4	2.0	9.3	7.3	6.4
22	121.9	121.6	120.9	1.9	11.8	9.7	9.1
24*	119.5	116.7	119.0	1.3	3.5	10.3	1.1
27	112.3	111.4	110.3	2.0	6.7	4.6	2.6
31	104.3	105.0	105.5	1.2	4.4	3.9	2.0
34	99.3	98.6	97.6	1.7	7.5	5.0	6.9
37	93.7	94.2	92.7	1.5	5.2	2.3	7.3
39	85.3	86.6	83.5	3.1	4.7	4.8	7.5
41	83.7	82.6	79.0	4.7	5.9	6.5	6.6
Westside Bridge	77.3	74.9	76.2	2.4	13.5	0.7	1.9
45	67.6	68.2	68.9	1.3	20.2	17.8	2.5
46	60.5	61.5	61.1	1.0	12.5	9.8	10.6
47	59.2	57.4	59.2	1.8	7.7	9.6	4.2

- 1 Stations are Corps of Engineers' "Ranges" shown on plate 3.
- 2 Thalweg elevations are shown at the station and at locations 200 feet upstream and 200 feet downstream from the station (400-foot reach of the channel).
- 3 Maximum difference is between the highest and lowest elevation between the three stations (400-foot reach of the channel).
- 4 Shows maximum apparent thickness of channel deposits above thalweg at each station and between stations (400-foot reach of the channel).

* Station #24 is at Lambert Bridge

Table 2. Vertical changes in Dry Creek channel between 1974 and 1975.¹

Station ²	Thalweg (in feet)	Channel ³ (average of cross section)	Station ²	Thalweg (in feet)	Channel ³ (average of cross section)
Bord bridge	+2	+	22	0	0
Bord Bridge	+2	+	22	+1	+
2	-3	0	22	0	-
2	-1	0	24	-1	0
2	0	-	24	0	0
2A	+1	0	24	0	0
2A	0	0	27	0	0
2A	0	-	27	0	0
4	0	0	27	0	0
4	0	0	31	+1	-
4	-1	-	31	+1	0
5	0	0	31	0	0
5	-1	0	34	0	-
5	0	0	34	0	+
7	0	0	34	0	0
7	+1	0	37	-3	0
7	0	0	37	-2	-
8	0	-	37	0	-
8	+1	+	39	0	-
8	+1	0	39	-2	+
Yoakim			39	0	-
Bridge	-3	-	41	-1	-
"	-1	0	41	-2	-
"	+1	-	41	+1	0
11	0	0	Westside		
11	-1	0	Bridge	-3	-
11	-3	-	"	-3	0
13	-1	-	"	-9	-
13	0	-	45	-2	0
13	-1	-	45	-1	-
15	-1	-	45	-2	-
15	-1	-	46	0	-
15	0	0	46	0	0
18	+1	+	46	0	-
18	+1	+	47	-1	-
18	+1	+	47	0	0
			47	0	0

1 Data from U.S. Army Corps of Engineers (1974); Surveys made in early summer of each year.

2 Stations are numbered in sequence downstream; at each station three sections were surveyed across the channel (except Bord Bridge); the principal section, and one section 200 feet upstream, and one section 200 feet downstream.

3 Aggrading +; Degrading -; unchanged 0.

Table 3. Recent floods and fires along lower Dry Creek.

FLOODS ¹			FIRES	
Year	Water Year ²	Runoff ³	Year	Drainage Area
1955	1956	15,000?	1959	Mill Creek
1962	1962	13,100		
1963	1963	15,300		
1964 ⁴	1965	18,800	1964	Grape Creek
			1970	Schoolhouse Creek
			1972	Bradford Mountain
1974	1974	19,400		

1 Greatest floods of record

2 From October 1 to September 30

3 One day maximum discharge in cfs

4 The flood of 1964 followed the fire in the Grape Creek drainage by 3 months

Flood data for 1955-1964 from: U.S. Army Corps of Engineers
(1967, p.7)

Flood data for 1974 from: U.S. Geological Survey (1974, p. 417)

Fire data from: California Department of Forestry, Sonoma
Ranger Unit, Santa Rosa

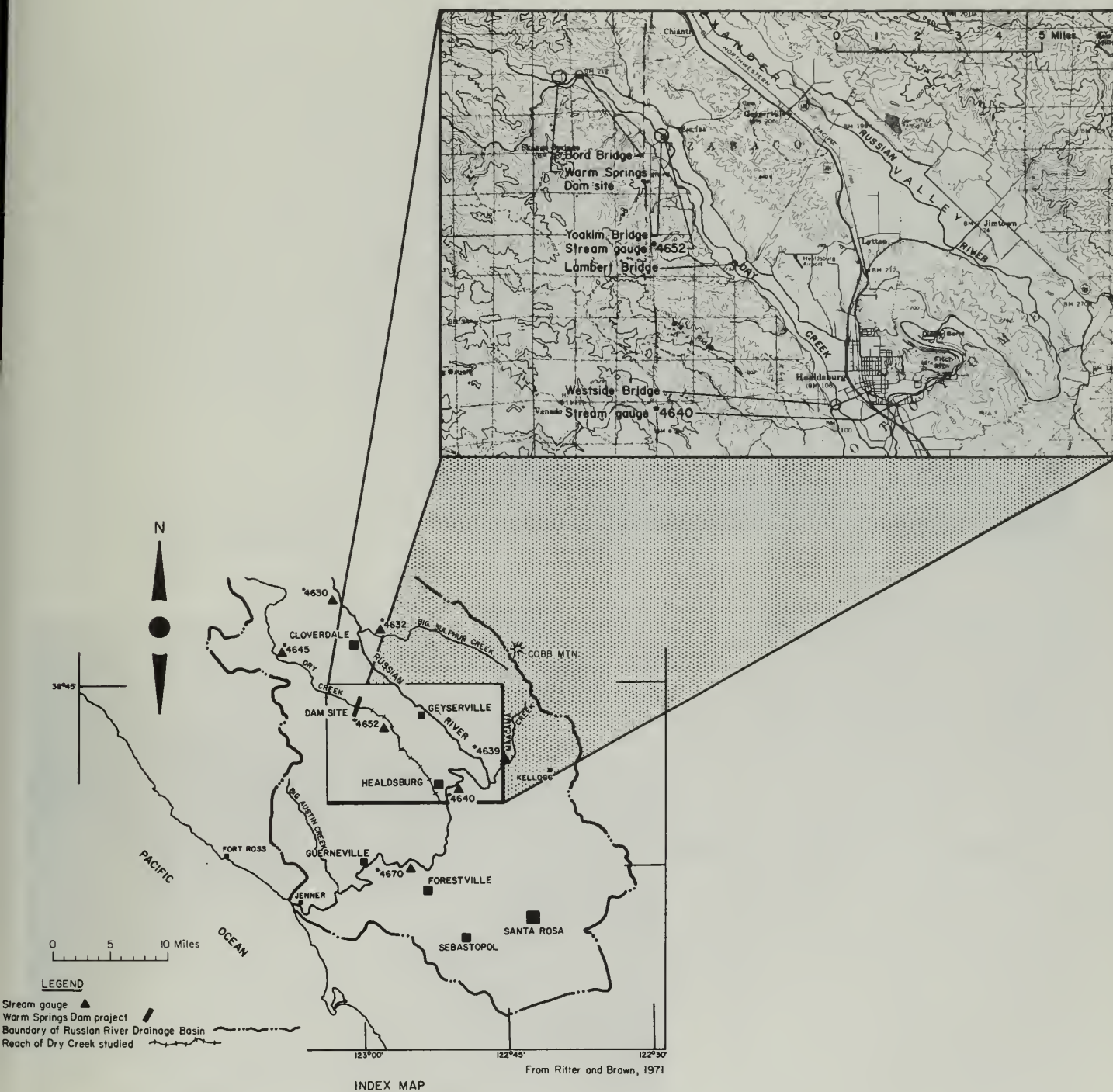


Figure 1. Russian River drainage system and location map.



A



B

Figure 2. Bank erosion on Dry Creek 1/3 mile north of where Grape Creek enters the main channel. (A) Erosion damage on the east sides of Dry Creek; view south. An orchard occupies the terrace on the left. (B) View eastward from southern end of terrace shown in A. Erosion has cut into the orchard acreage on the stream terrace. The well casing exposed in the stream bed was formerly on the terrace several feet back from the edge of the creek bank. Photos by Frederic R. Kelley, 1975.

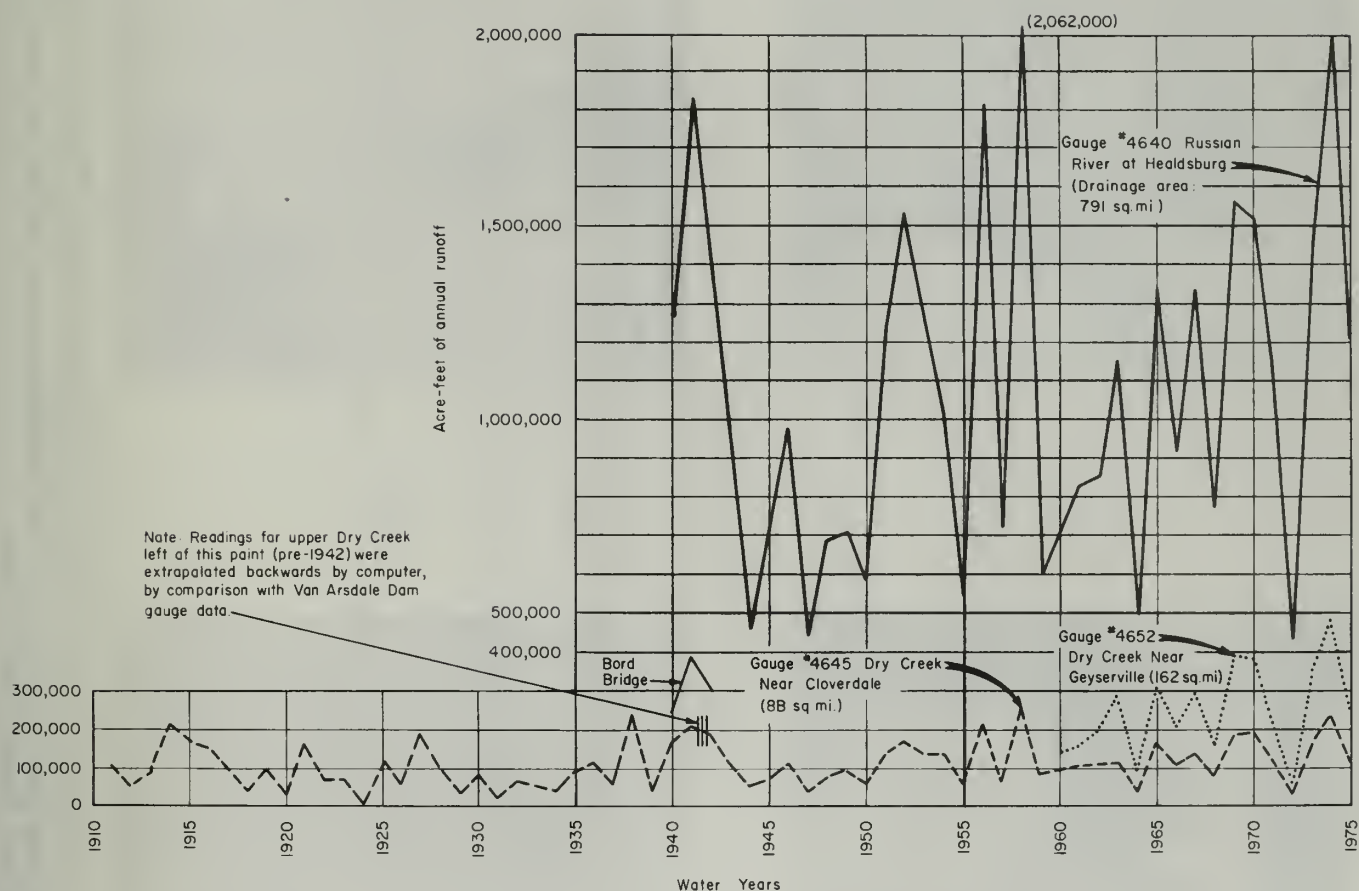


Figure 3. Total annual runoff based on the water year (October through September) for gauges in the Dry Creek area.



A



B

Figure 4. Westside Bridge on Dry Creek, July 1975. For location see figure 1. Since 1953 gravel mining has increased in the vicinity of this bridge. (A) Eleven feet of erosion in the channel of Dry Creek at the bridge has undermined the footings and exposed the tops of the pilings. Inset: close-up view of center piling. Photos courtesy of Dr. B.J. Olson. (B) Westside Bridge on Dry Creek, after repair; January 1976. Inset: close-up view of the center piling. Photos by Frederic R. Kelley.

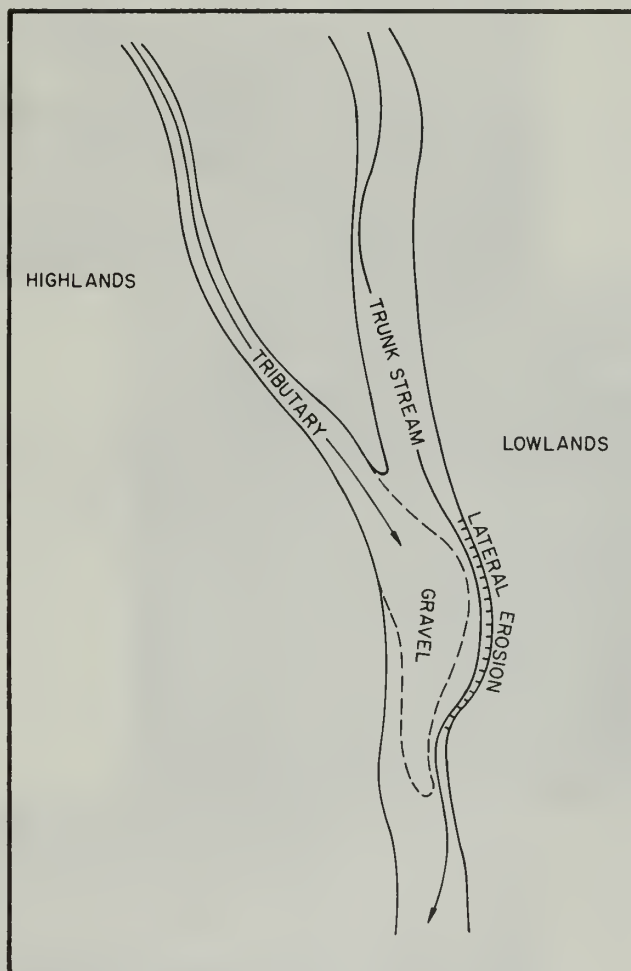


Figure 5. Lateral erosion of trunk stream channel by the deposition of debris (gravel) from a tributary stream.

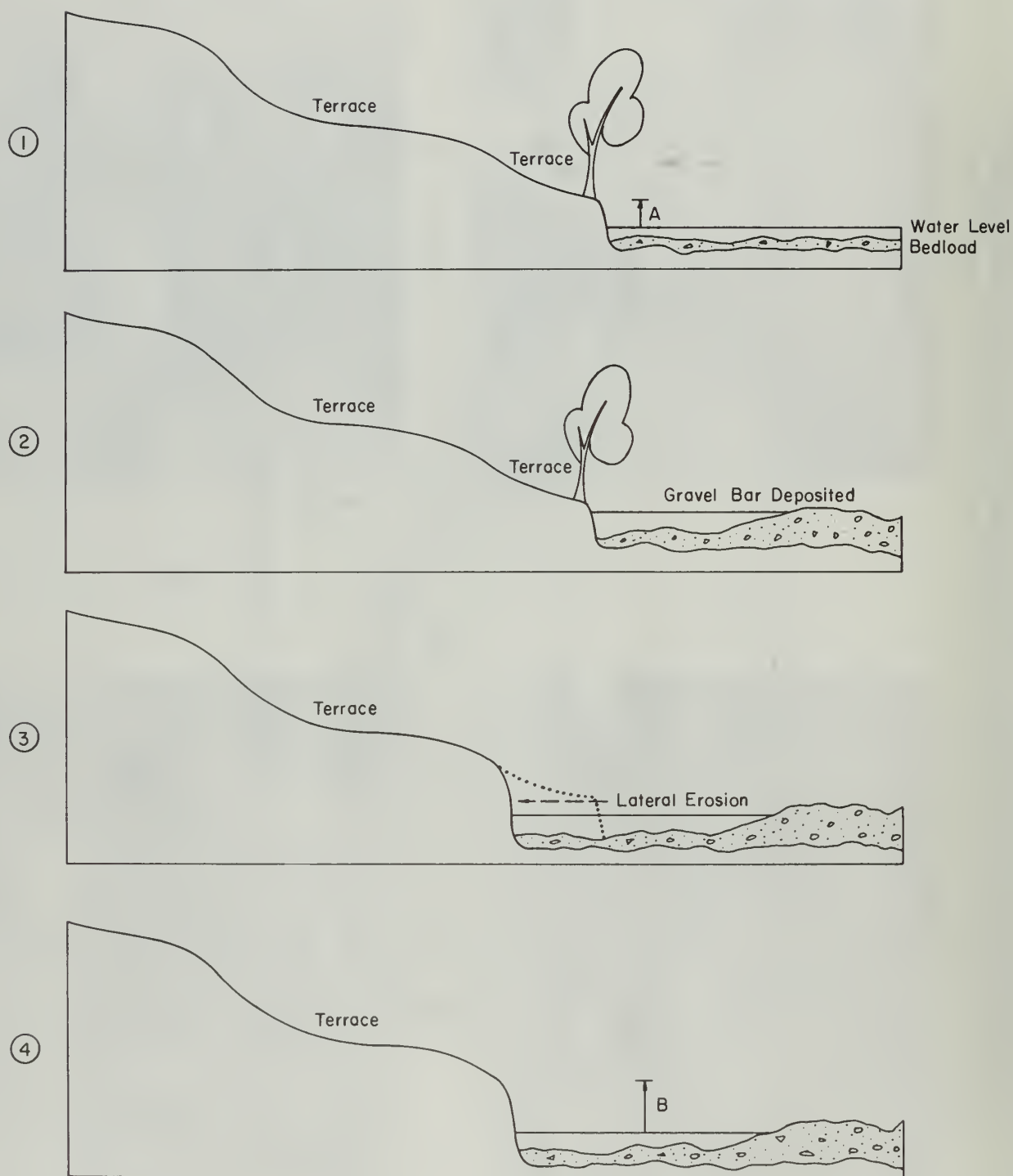


Figure 6. Diagrammatic sections illustrate how lateral erosion yields higher banks (1-A, 4-B) as each higher terrace level is reached, giving the false impression that the stream bed is being lowered. (1) The stream channel is relatively stable with riparian vegetation growing along the banks. (2) Excess gravel carried into the channel forces the stream flow against the bank. (3) The terrace material, being relatively easier to erode than the gravel bar, gives way along with the vegetation. (4) The stream cuts into a relatively higher terrace, increasing the height of the bank (B) with respect to the original height shown in 1-A.



A



B



C

Figure 7. Erosion on Dry Creek near Pine Ridge Creek, about 1.5 miles upstream from Westside Bridge. (A) In an effort to protect a low stream terrace from erosion, rows of pilings were placed along the bank and cabled together. The stream flow bypassed each row and formed a new channel (left quadrant of photo) on the other side of the pilings. View northward; west side of Dry Creek on left, March 1960. (B) Close-up view of the eroded bank of the new channel, which was formed when the stream bypassed the pilings seen on the right and in A, March 1960. (C) Conditions of the stream bed seen in A and B after fifteen years. Additional erosion has occurred on the stream bank. Remnants of the pilings shown in A and B are visible in the stream channel. July 1975. *Photos courtesy of Dr. B.J. Olson.*

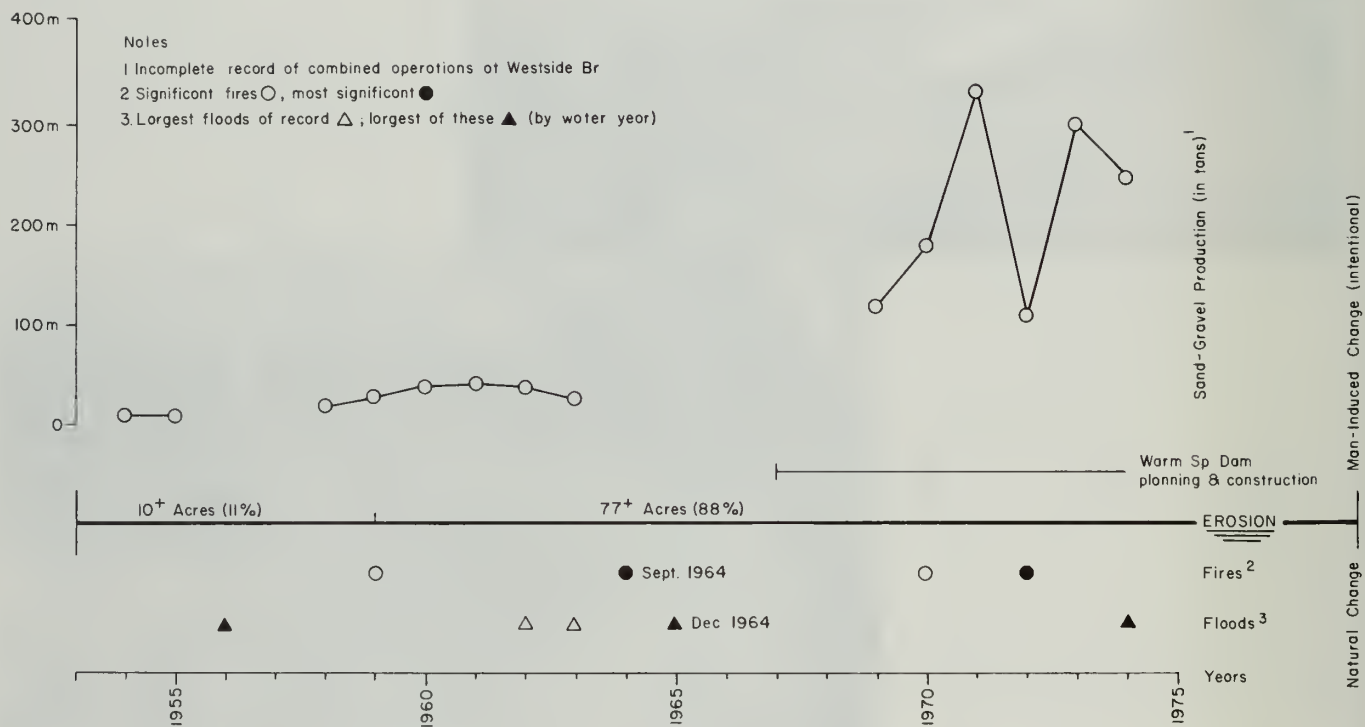


Figure 8. Dry Creek drainage area. Time-event relationship for erosion, fires, floods, gravel production, and dam construction.

A
ICY
VATION

SPECIAL REPORT 134

PLATE I

55' R.10 W

R 9 W.

122°52'30"

38°45'



AREAL-SPACE RELATIONSHIPS, PRECIPITATION, FLOOD AND FIRE MAP, DRY CREEK AREA, SONOMA COUNTY, CALIFORNIA

EXPLANATION

Annual Precipitation-Isolyets:
from U.S. Army Corps of Engineers (1967)

48 inches

Storm Precipitation-Isolyets, 1964 storm
from U.S. Army Corps of Engineers (1967)

10 inches

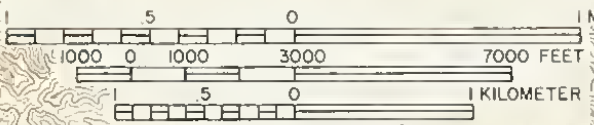
Flood Prone Area-100 year storm: from
U.S. Geological Survey (unpublished)

Drainage Sub-basins

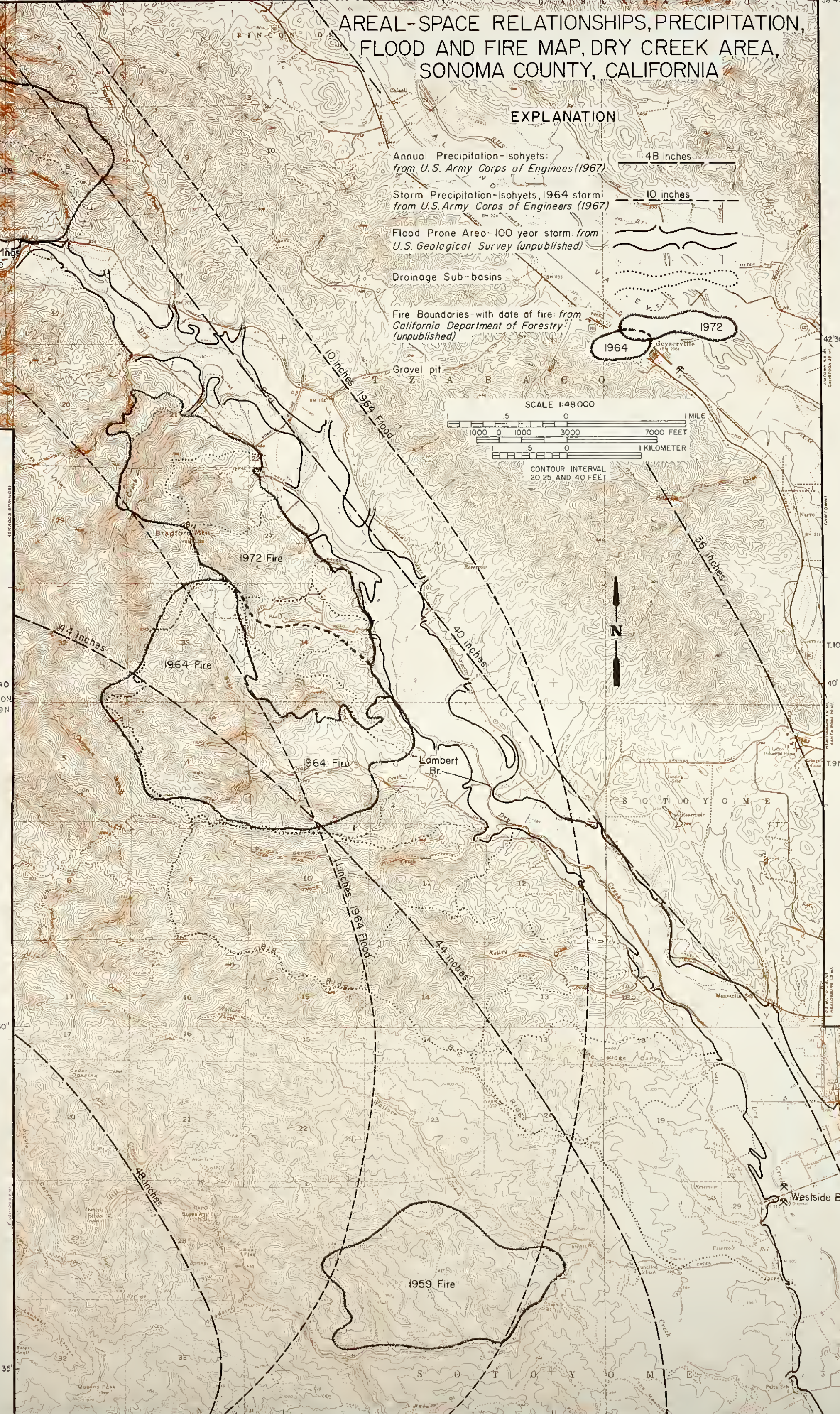
Fire Boundaries-with date of fire: from
California Department of Forestry
(unpublished)

Gravel pit

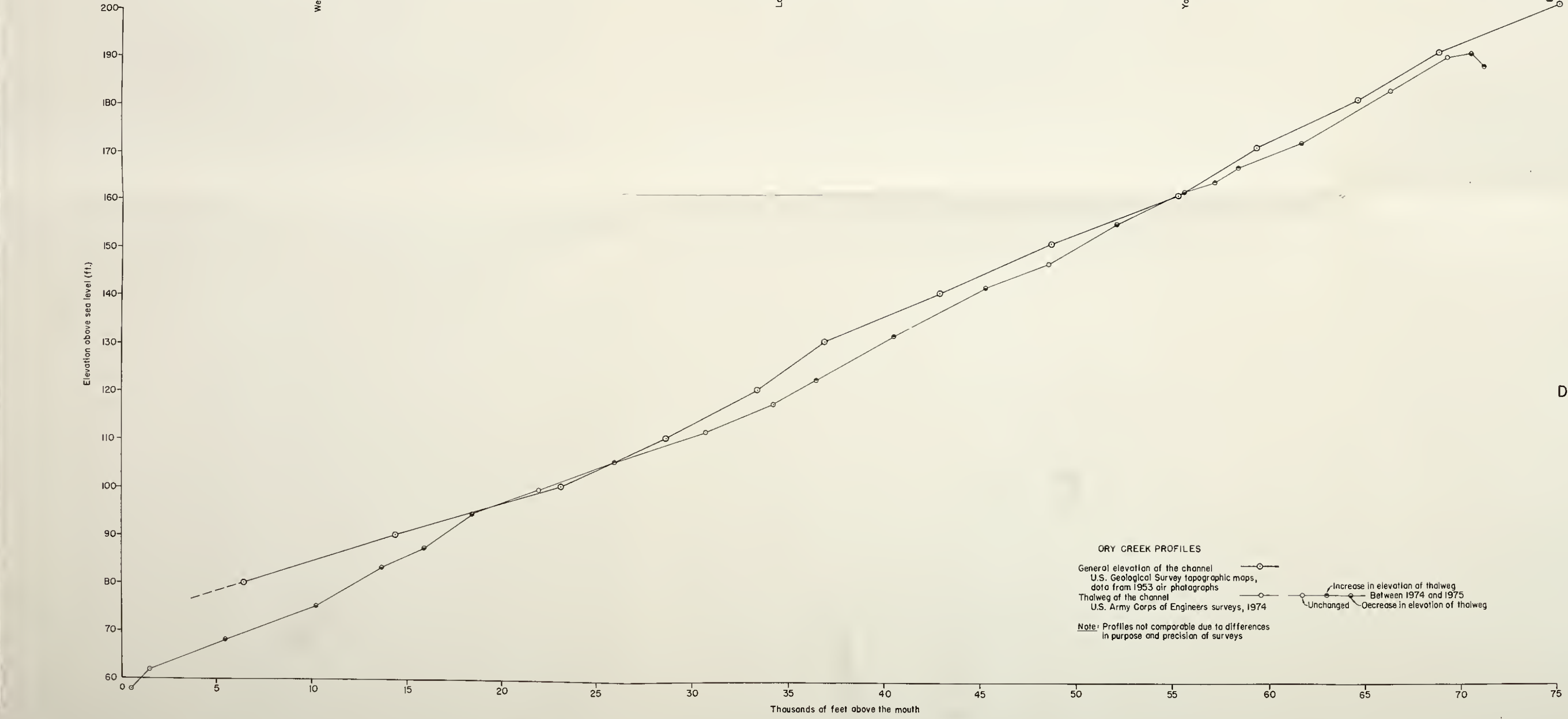
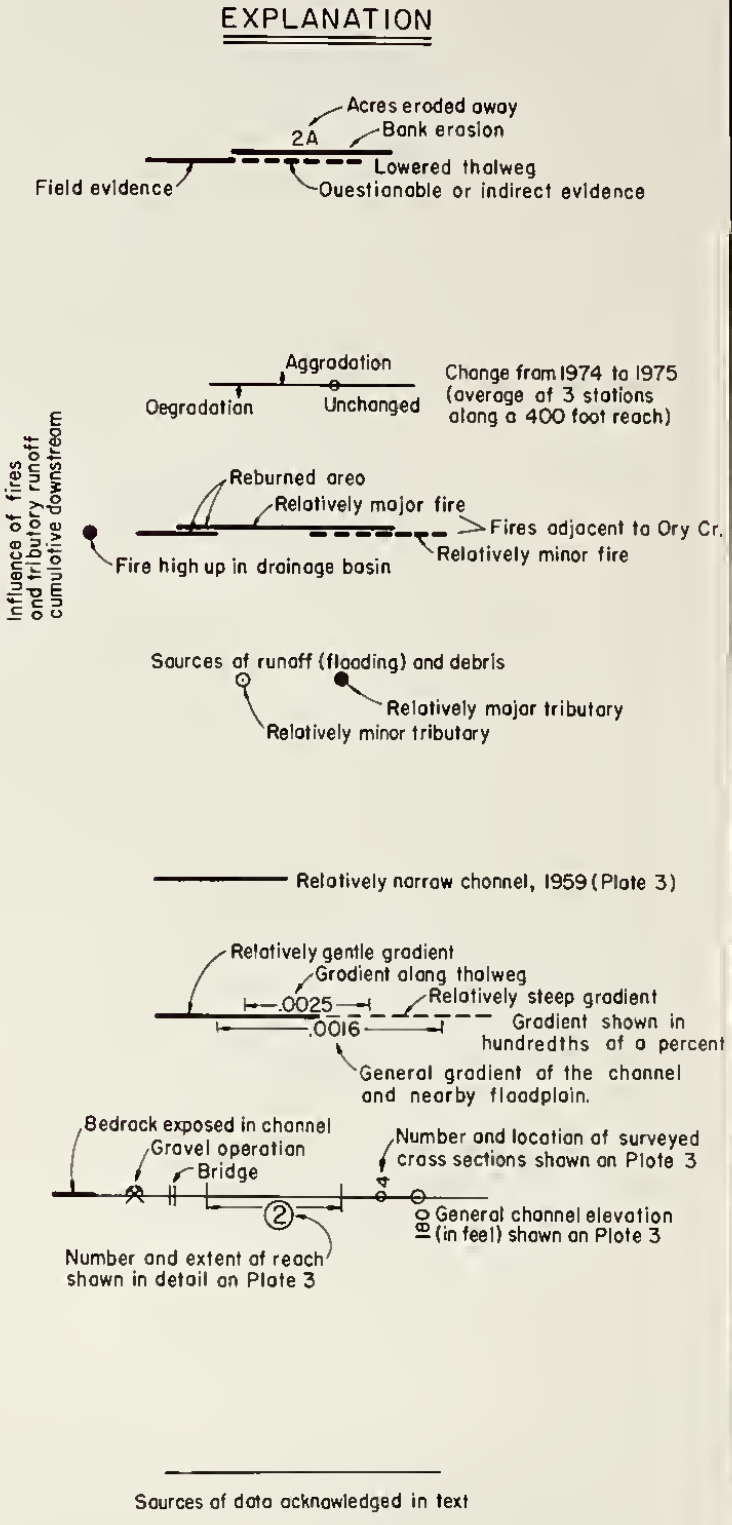
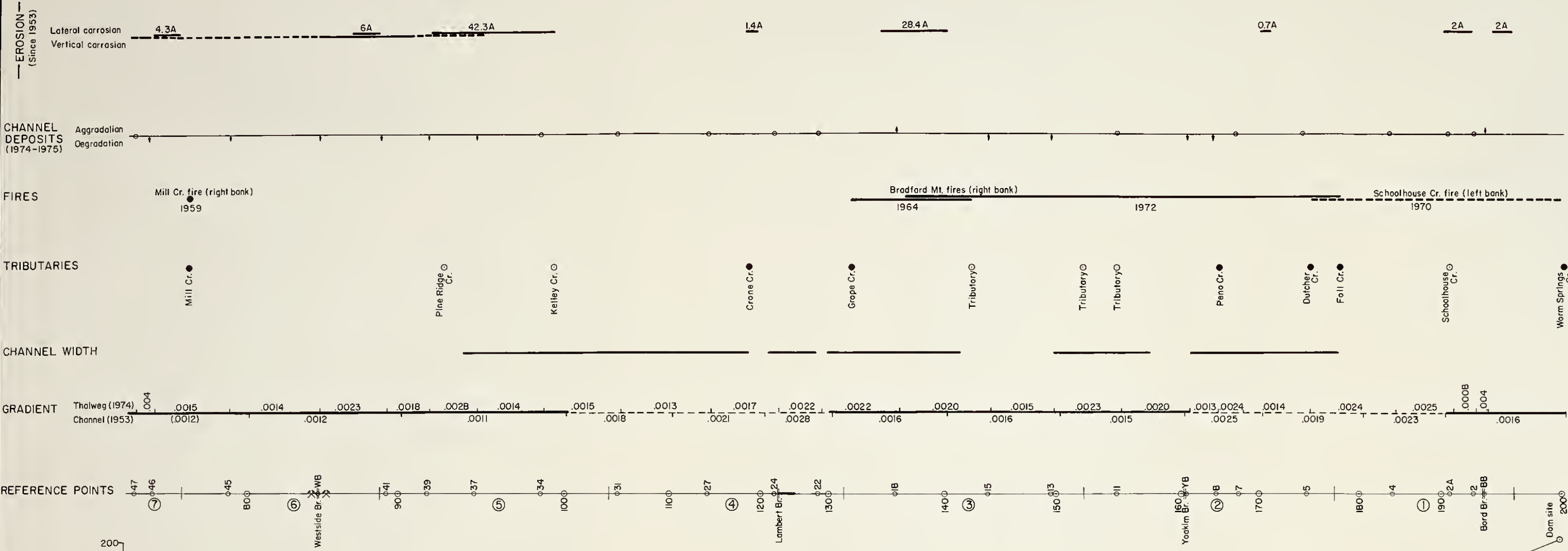
SCALE 1:48 000



CONTOUR INTERVAL
20, 25 AND 40 FEET

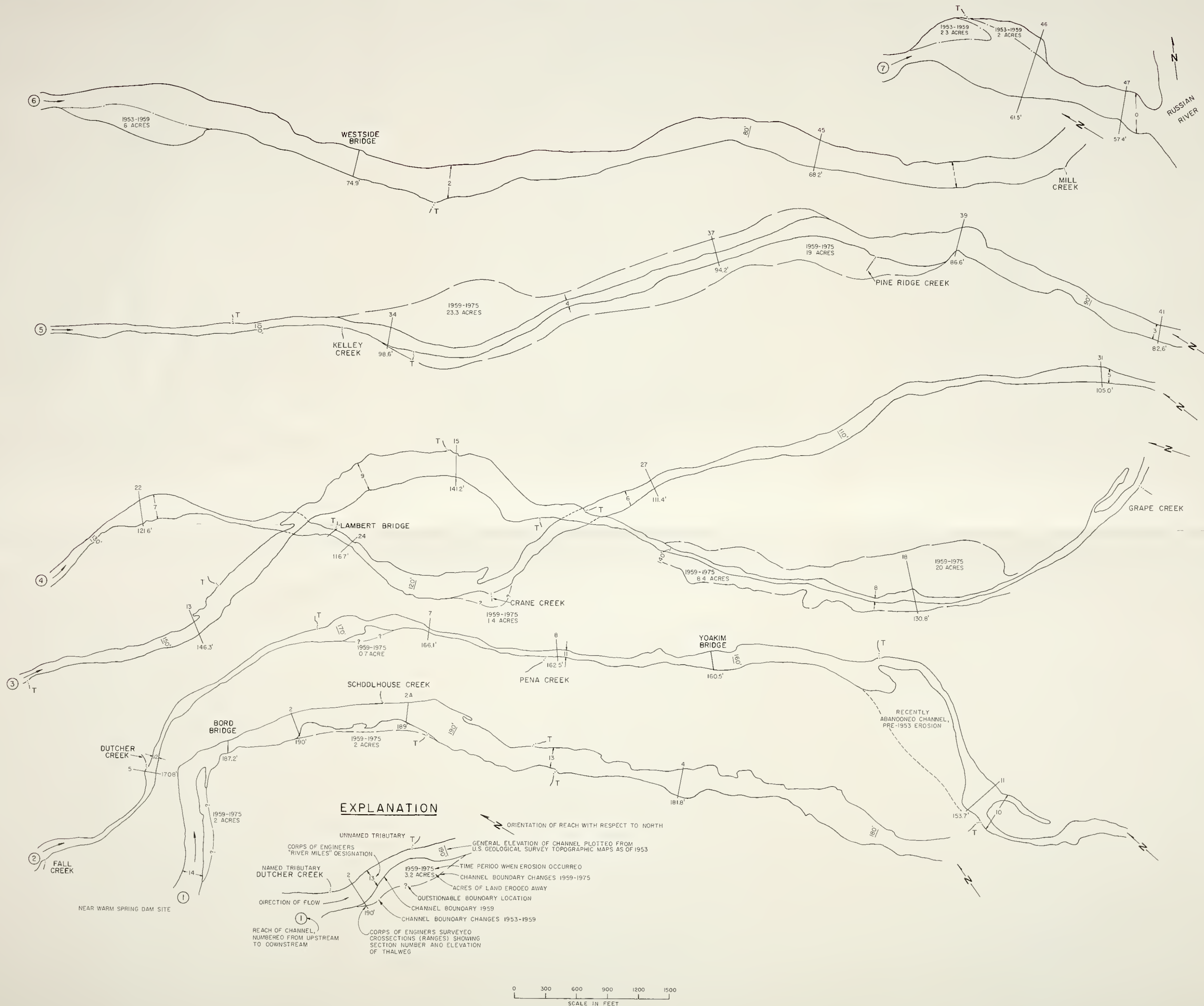


LINEAR ELEMENTS



LINEAR-SPACE RELATIONSHIPS,
DRY CREEK, SONOMA COUNTY, CALIFORNIA





CHANNEL OF LOWER DRY CREEK, SONOMA COUNTY, CALIFORNIA, — 1959

